

# A Programmatic Approach to On Condition Maintenance

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# Background - Where we started



- Purchased 80 COTS Honeywell Model 8500C Balancer/Analyzer, as existing equipment was not supportable (1.56 M, FY 96)
- Engine Front Frame Cracking #1 Safety Issue
  - Vibration due to poor RT&B causing cracking
  - Excessive #1 Bearing oil leakage, ingested by engine, caused in-flight emergency engine shut downs
  - Costs squadron man-hours and engine replacement
- Premature structural and hinge point failures experienced
- New RT&B procedure successfully developed to eliminate engine front frame cracking
- DCC-81 Modified rotor blades (105K, FY 97)
- Elimination of Whirl Tower saved \$5M Annually

Drive to utilize equipment to its capacity

# **Phase I**

## **Getting Started and Setting the Foundation**



# Initial Testing and Instrumentation



- COTS equipment could collect vibration data
- COTS software needed to automate the O level aspect of the analysis
- Develop the frequency models of the engine and drive train
- Optimize sensor locations through surveys and initial testing
- Collect data that can help establish good vibration limits
- Validate the system approach before fleet implementation

- Merely collecting data without having tools to drive real world interpretation will lead to failure
- Limits and data collection sequences must be modifiable by the Navy Engineering Staff
  - Older Vibration Equipment required the vendor to modify software any time a change was needed
- Software should keep it simple for the end user
- Maintenance manuals should interface with analysis system

Analysis Software is Key

# System Training



- Teach the theory, not just the how
- Instructional and practical/hands-on methods required
- Share results
- Empower the user to be a part of the system developments/enhancements
- Technical representatives at the sites are key to success

Communicate system benefits through training

# **Phase II**

# **Periodic Vibration Checks**



# Slow methodical implementation



- **100 hour/phase checks increased knowledge**
- **Gained momentum as troubleshooting tool**
- **Maintenance time decreased**
- **Data review identified issues we never could have seen with previous test methods**
- **Allowed us to evaluate effectiveness before spending a lot of money**
- **Avoids false removals / A799 rates**
- **Able to grant high time component life extensions**
- **Fleet demand drove follow-on buy of 30 more 8500C units (780K, FY 98)**

**Early steps realized significant savings**

# Five Significant Case Examples



- **High Speed Shaft Resonance**
- **High Speed Shaft Adapter Imbalance**
- **Main Electrical Generator failures**
- **Service life extensions for aft transmissions**
- **Excessive engine vibrations**

# High Speed Shaft Resonance



## Problem

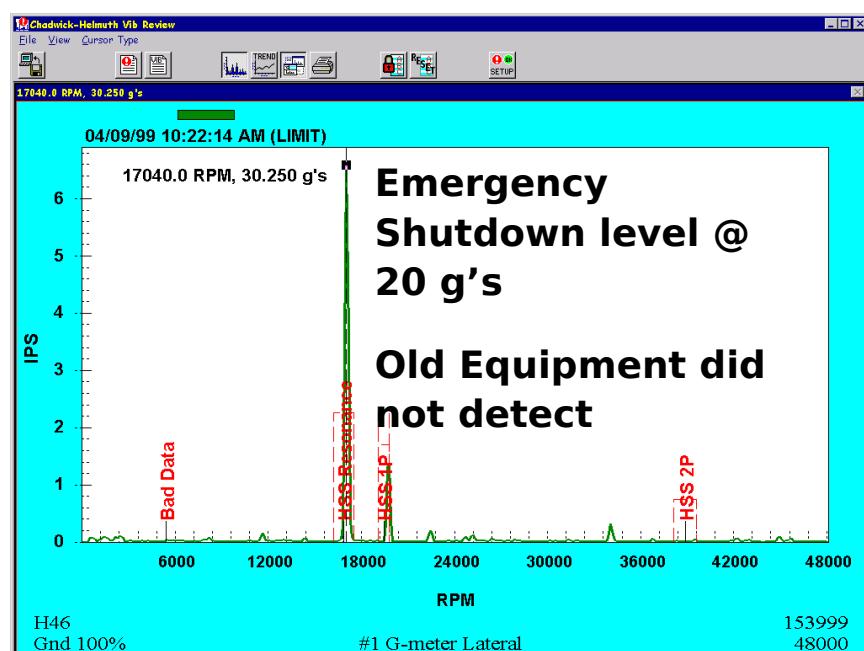
- Damaged torque sensors
- Erroneous torque readings

## Findings

- Spline wear allowing resonance in HSS
- HSS resonance undetected with previous equipment
- Pilots troubleshooting by throttling the engine back and causing resonance
- Spectral analysis equipment can detect resonance

## Resolution

- Inspection of spline wear implemented
- Check for resonance with use of narrowband equipment when erratic torque readings reported
- Pilots instructed to operate at 100% Nf/Nr



# High Speed Shaft Adapter Imbalance



## Problem

- Increase in shaft removal & rejection
- Seals failing
- Engines and transmissions were being removed

## Improperly Balanced Adapter

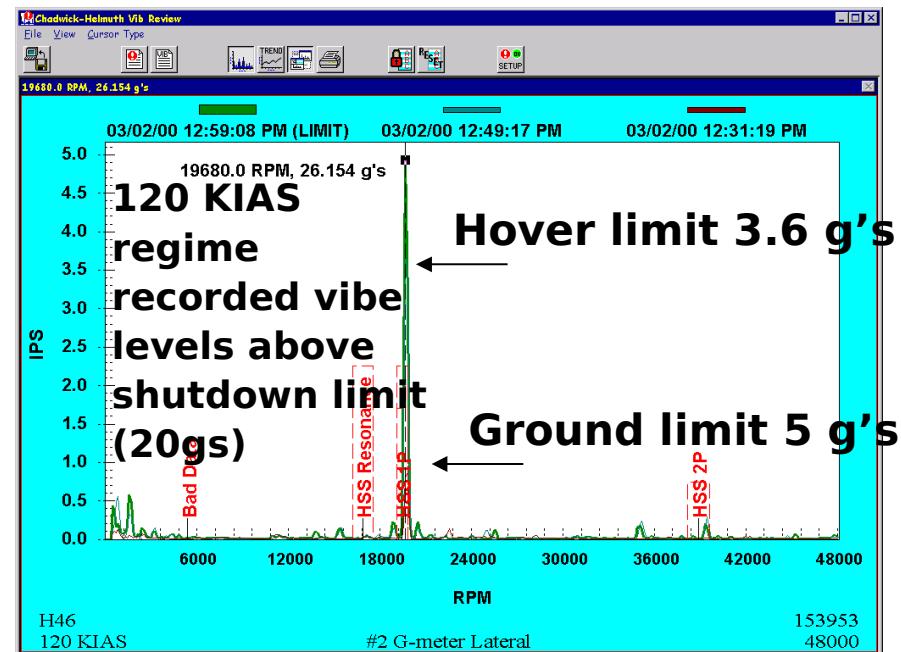


## Findings

- Periodic vibration checks expanded to in flight regimes revealed HSS levels as high as 26 g's
- Balancing procedures at vendor and depot facilities found to be inadequate

## Resolution

- Balance machines updated and match set balancing implemented



# Electrical Generator Failures



## Problem

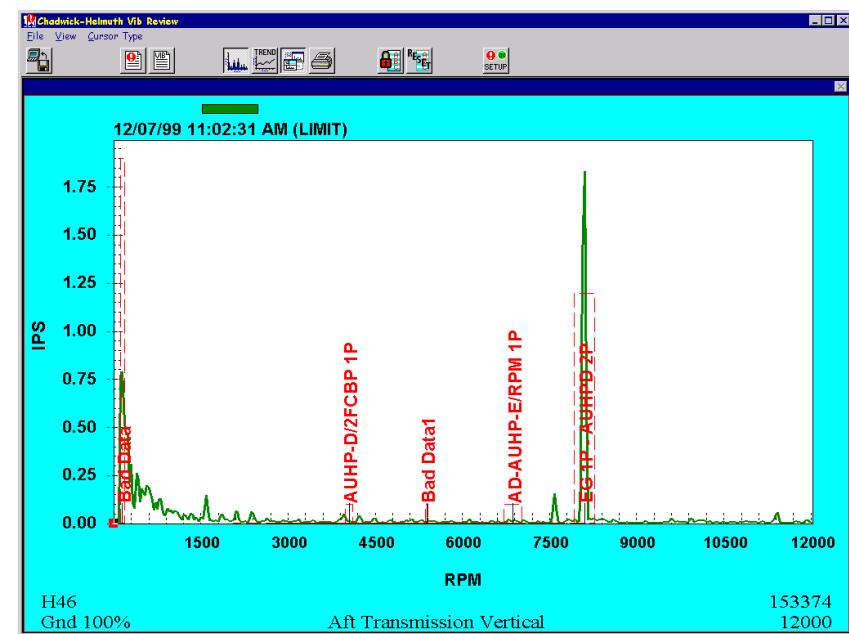
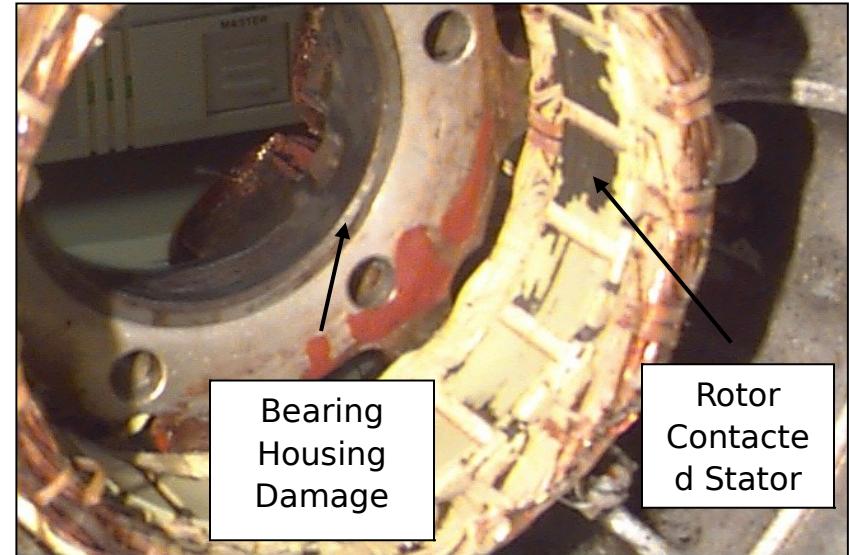
- Catastrophic generator failures
- Failures causing in-flight hazards & emergency shutdown

## Findings

- Change in scheduled maintenance allowing generators to run to failure

## Resolution

- New vibration check procedure identifies degraded generators before catastrophic failure
- Scheduled overhaul replaced with vibration check (on-condition)
- Saves ~900K per year



# AFT Transmission Life Extensions



## Problem

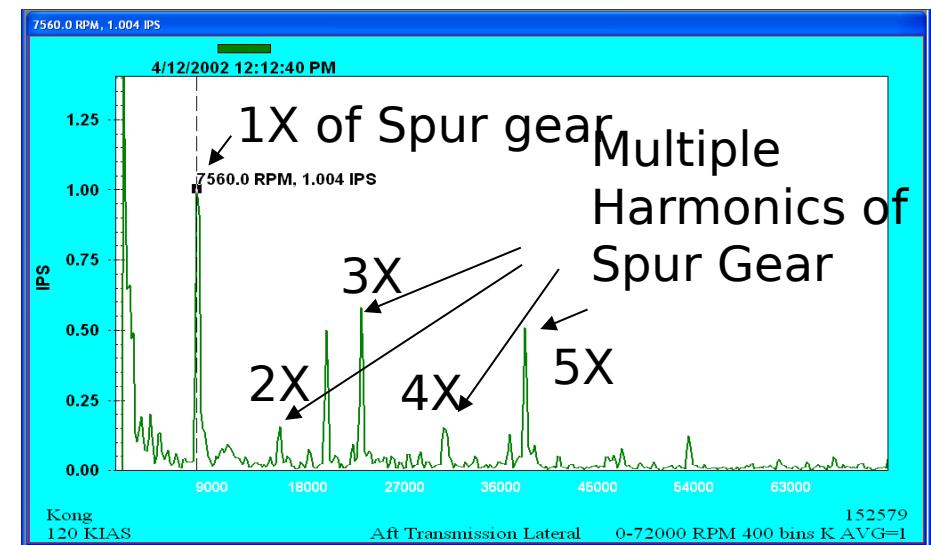
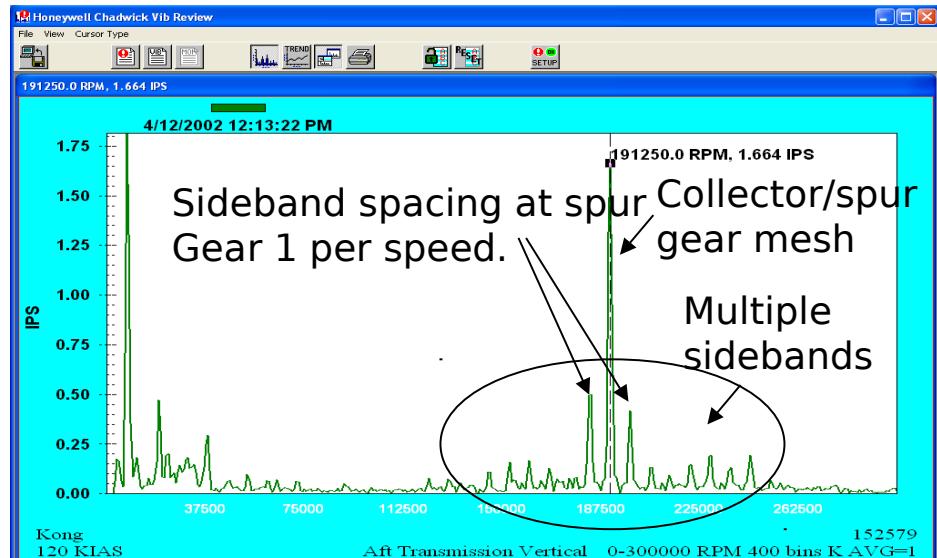
- High time of Aft Xmsn is 900 hours
- Life extensions granted without data
- Untimely failures resulted

## Findings

- Failures can be detected by vibration analysis

## Resolution

- Mandatory submittal of vibration data required for life extensions
- If able to eliminate resonance the Xmsn may be able to extend to 1800 hours



# Excessive Engine Vibrations



## Problem

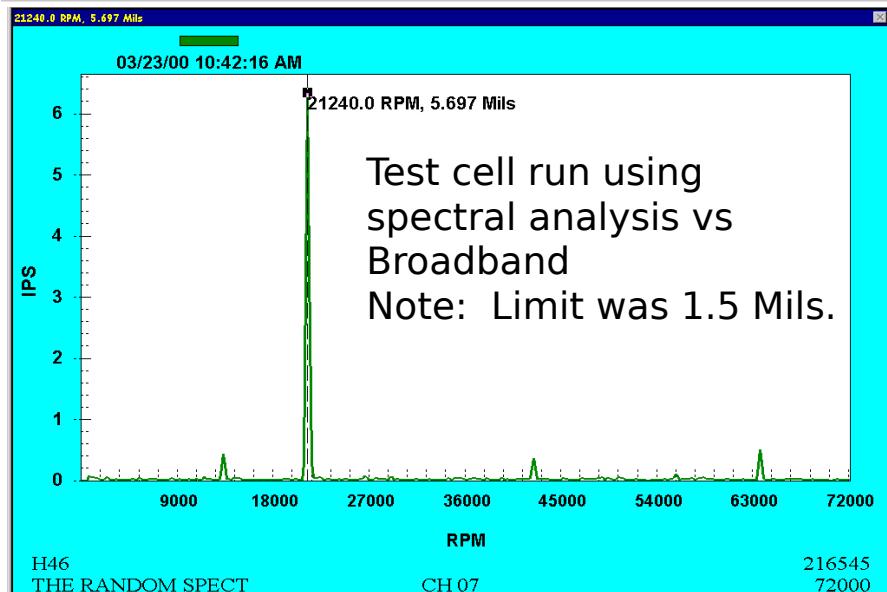
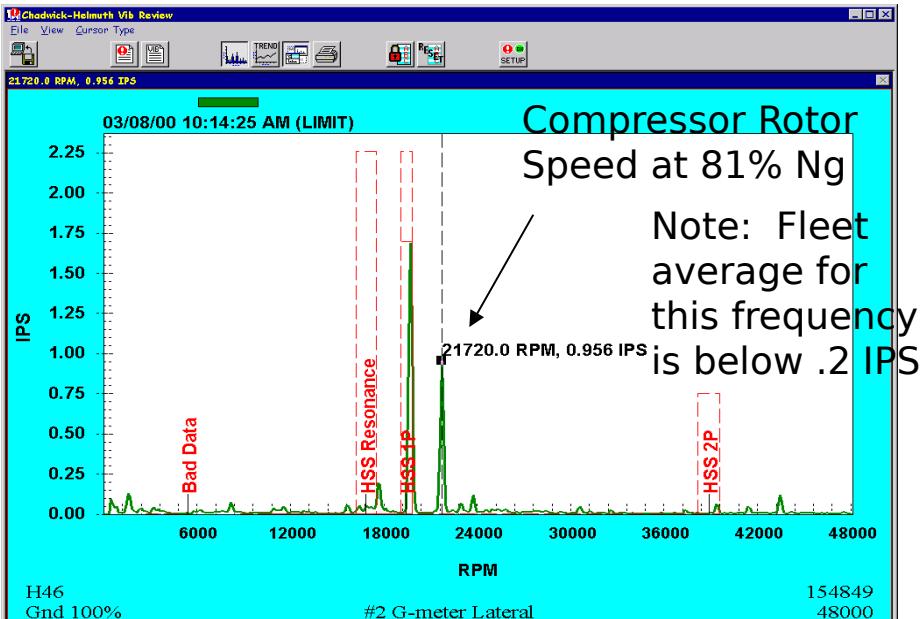
- Loud audible howl on newly overhauled engine

## Findings

- All test cell runs passed
- Mils Broadband was acceptance criteria
- Mobile test cell failed to identify problem
- Poorly balanced compressor rotor caused damage to 8<sup>th</sup>, 9<sup>th</sup>, and 10<sup>th</sup> stages of the rotor

## Resolution

- 3 spectral analyzer fielded in test cells for data collection



# **Phase III**

# **Justification for Hardwiring of Aircraft**



# Eng Drive Shaft Catastrophic Failure

INVESTIGATION AIR

## Problem

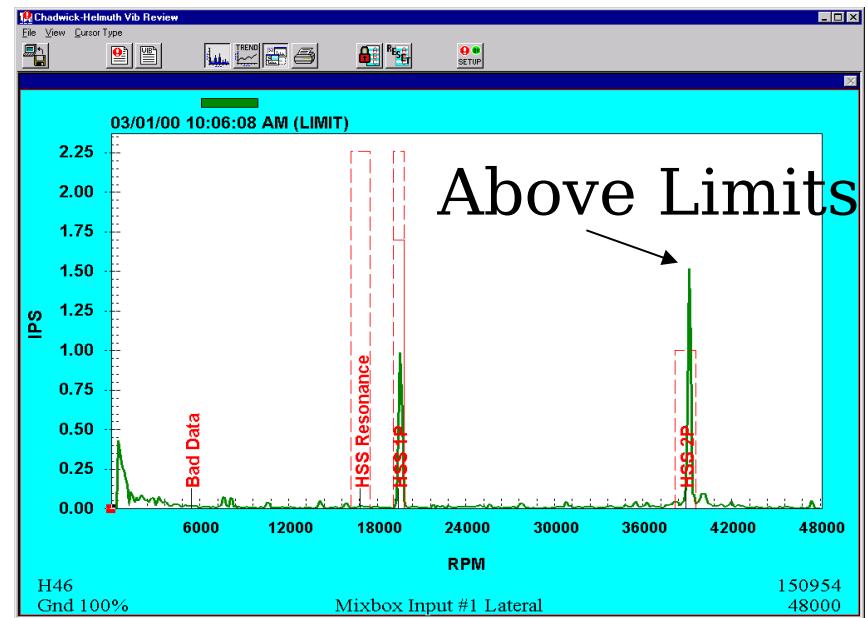
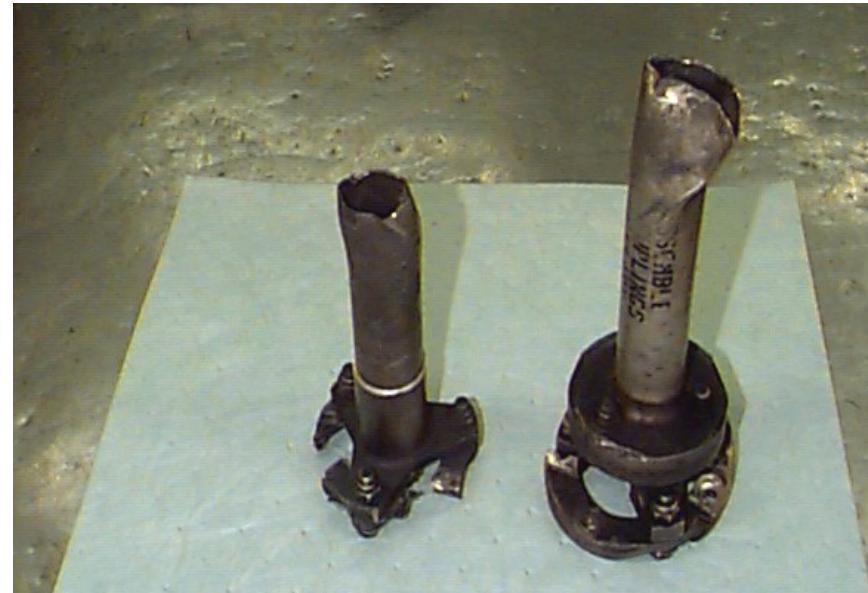
- Test of #1 & #2 Engine Drive Shafts indicated misalignment on Engine #1

## Findings

- Maintenance performed and aircraft released to serviceability
- #2 Engine Drive shaft failed catastrophically in flight
- Equipment installed incorrectly
- Maintenance performed on incorrect shaft

## Resolution

- Human error allowed component to fly to failure
- Hardwiring would have prevented this error



- Purchased kits to install sensors and wiring in approximately 180 aircraft (1.2M, FY 00)
- Prepares aircraft for onboard vibration system expansion
- Solved fleet driven complaints about SE wear and tear

# **Phase IV**

# **Test Cell Expansion**



# Initial Testing and Implementation



- **Began initial data collection using 3 8500C spectrum analyzers in late 1999**
  - 2 at NADEP Cherry Point
  - 1 at MALS-29/26
- **Noted significant gains by progressing towards spectral analysis**
  - Provided means to isolate specific frequency(s) yielding greatest amount of vibration
  - **Significant unbalance conditions noted on main rotating components**
    - ◆ New balance machines and procedures incorporated (350K)
- **COTS spectrum analyzers (VXP) fielded in early 2001 (235K, FY 01)**
- **Spectral analysis now used on all test cells to accept/reject engines**

# Older Vibration System Costs



- **Vibration data collected by Broadband system had falsely led fleet to reject multiple Power Turbine assemblies due to excessive vibration**
  - GE proposed an expensive redesign of the PT bearing/housing as a viable solution
- **COTS vibration analyzers uncovered the dominant frequency causing the vibration, which was the Gas Generator Turbine**
  - Immediately avoided countless PT overhauls (fleet wide)
  - GE ceased bearing redesign effort
  - Yearly savings realized, using spectral analysis, due to fault isolation capabilities
    - ◆ PT Rotor Cost: \$47,757/unit
    - ◆ PT Assembly Cost: \$99,264/assembly

# Substantial Finding - Impending Bearing Failure



## Problem

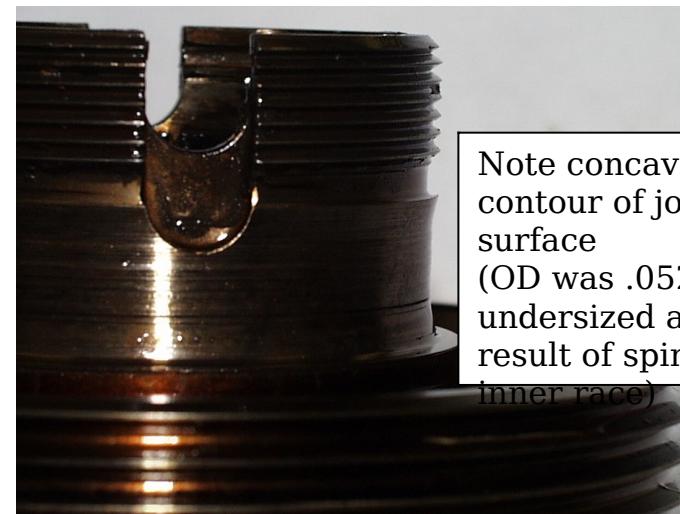
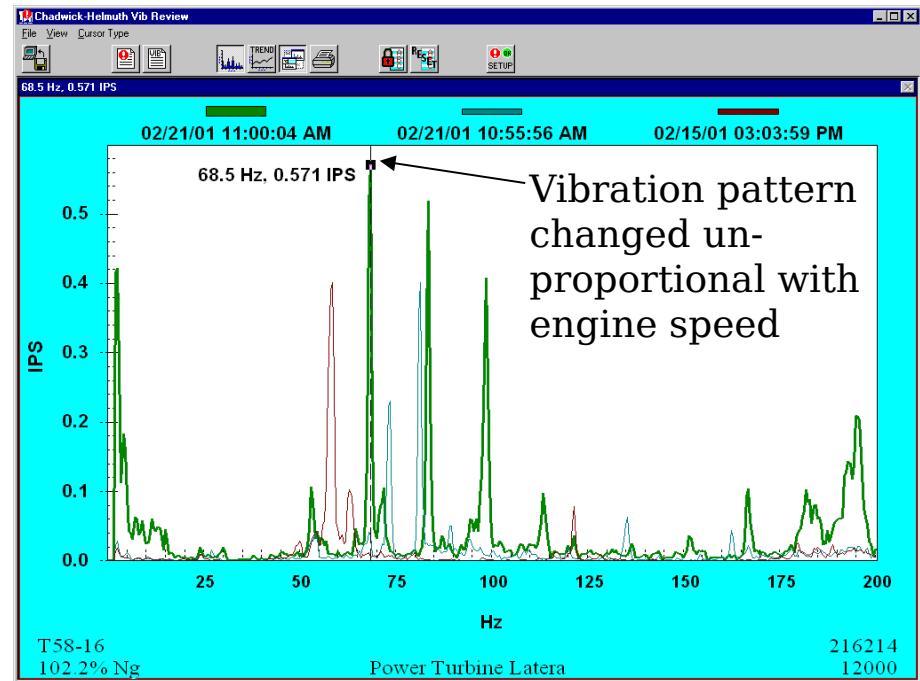
- Engine passed test cell based upon Broadband vibration test
- Rejected on-wing due to audible howling

## Findings

- Spectral analysis indicated Gas Generator Turbine as the problem area
- Troubleshooting with the spectral analysis concluded to non-synchronous behavior, indicating spinning bearing race
- Large fragments found upon teardown
- Test cell Broadband equipment not properly configured

## Resolution

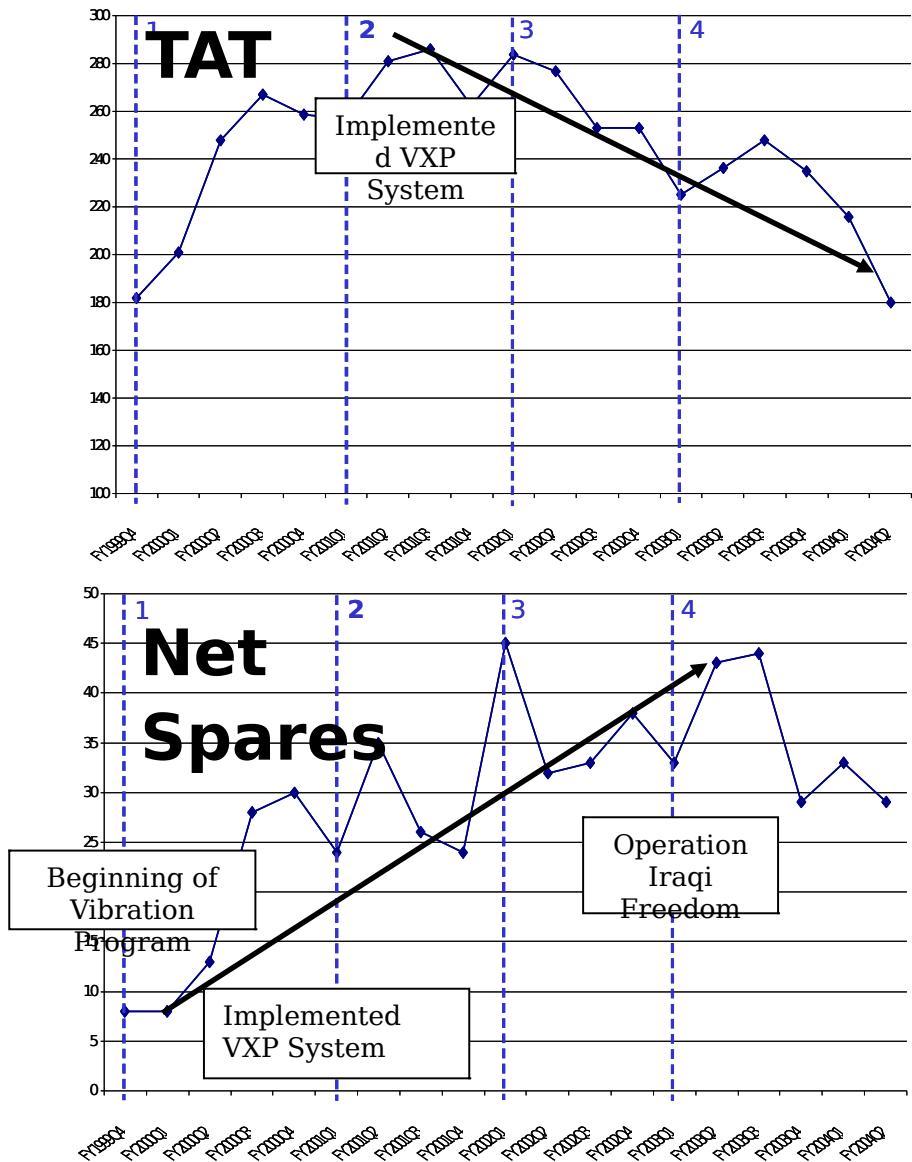
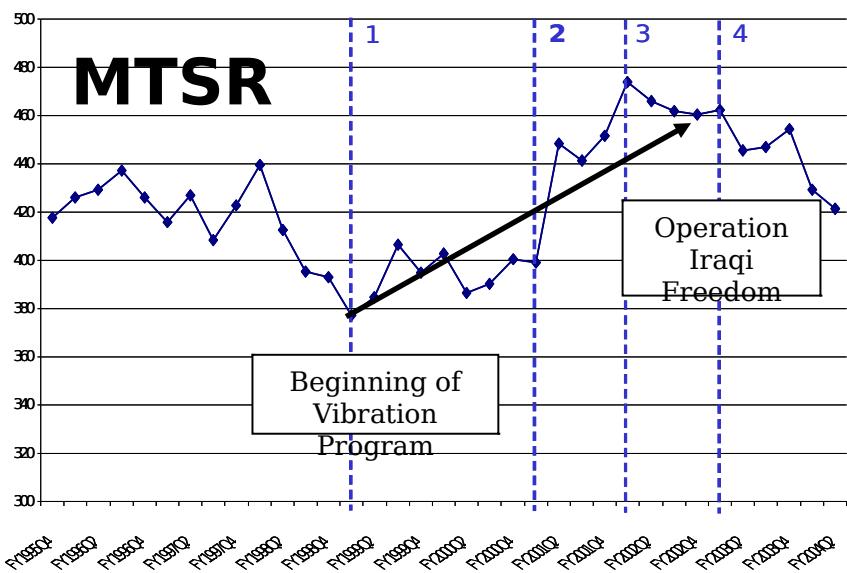
- Early detection of bearing wear possible with spectral analysis, avoiding potential catastrophic failure on-wing



Note concave contour of journal surface  
(OD was .052 in undersized as a result of spinning inner race)

# Return on Investment

- Spectral analyzer implementations yield significant benefits
  - Increased engine avg. mean time since repair
  - Decreased engine turn around time
  - Increased average net spares available



# **Phase V**

# **On-Board Systems Increase Safety**



# Aft Transmission Bearing Failure



## Problem

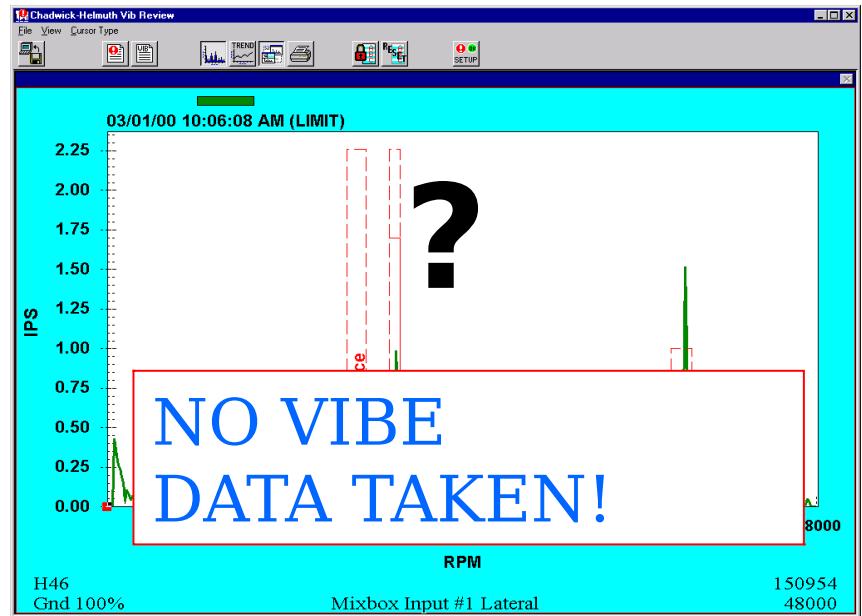
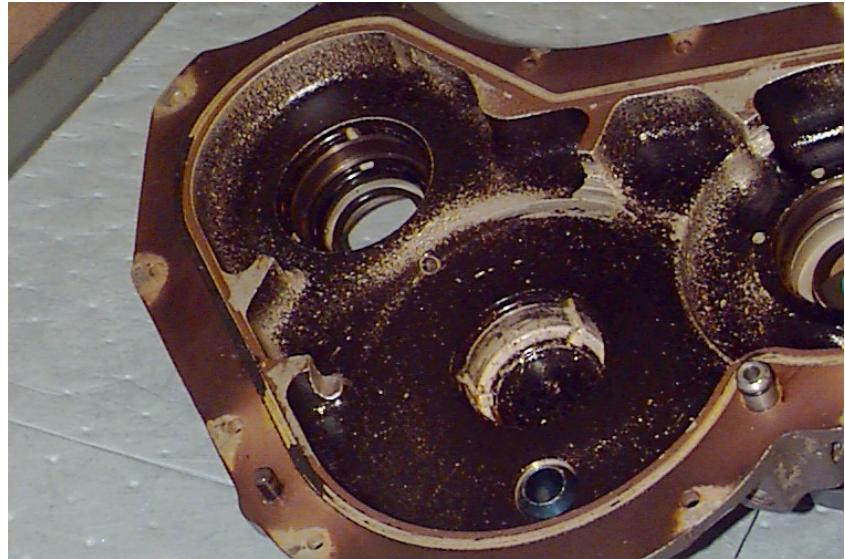
- Aft Transmission Smoking in flight

## Findings

- Bearing Failure
- Gearbox failed after bearing failure resulting in sheared lube pump shaft
- Loss of pump caused over temp in flight

## Resolution

- 100 Phase check was not performed
- Automated on-board system would have prevented this human induced error



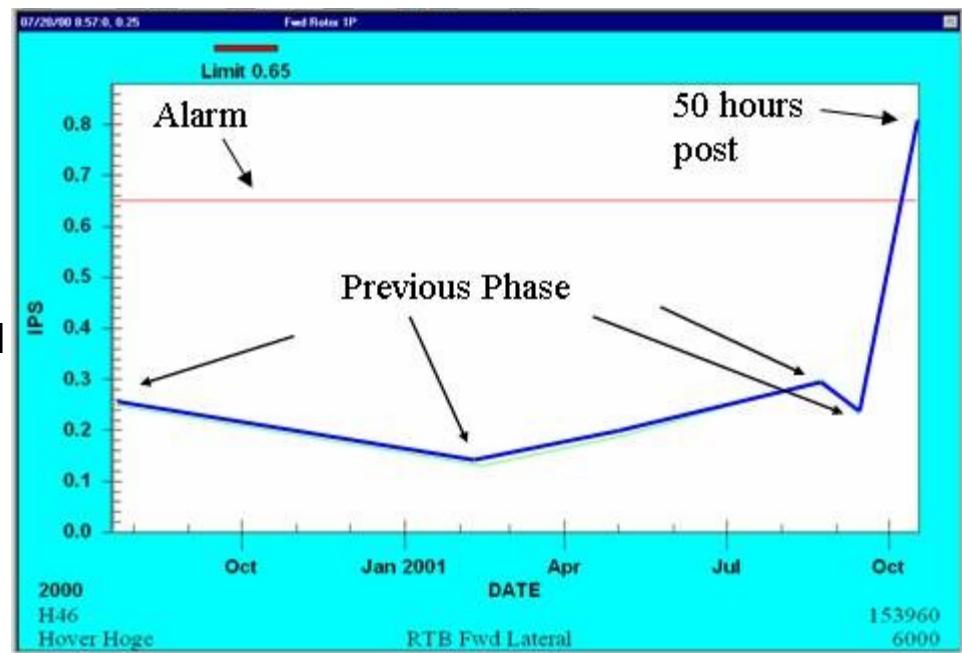
# Head Bearing Failure

## Problem

- Post Phase vibration checked and passed
- Significant increases in vibration reported by the crew after only a few hours of flight

## Findings

- Repeated vibration checks verified the crew discrepancy
- Vib levels had risen over a short period of time
- Sr. Squadron officer instructed the aircraft to remain in service
- 7 hours later the flight was aborted by the Air Boss - aircraft significantly shaking on deck
- Failed head seal and bearing found
- Oil leakage problem was ignored
- Lack of lubrication led to failure
- Rotor head hub was close to total failure that would have resulted in a complete loss of the aircraft & crew



## Resolution

- On-board equipment would have indicated the problem immediately

# **Phase IV:**

# **On Board System**

# **Aircraft Integrated**

# **Maintenance System**



# Eliminate Support Equipment



- Honeywell Rotor Track and Balance - Model 8500C+
- Vibration Signature Carry - On Accessory Kit
- Howell Instrumaster Engine Check System - NP600
- Purchased (FY 03 - 08)



Logistics Savings Realized

# Key Features Derive Solutions



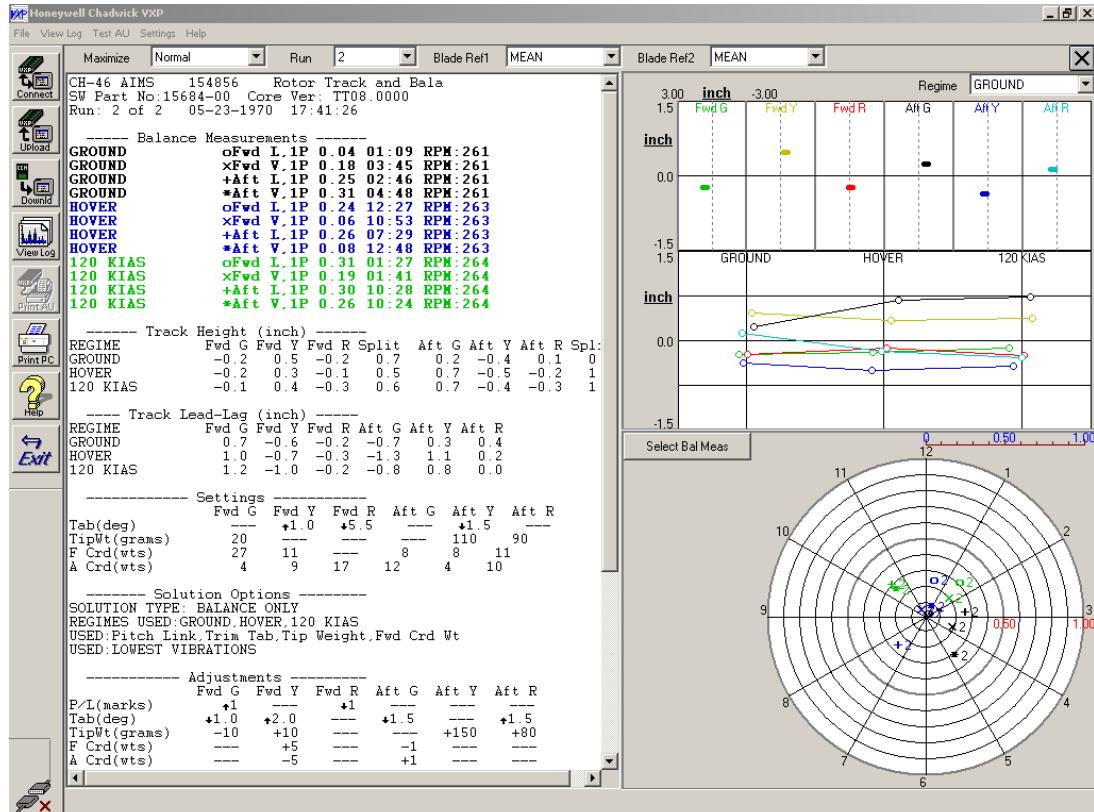
- Rotor Track & Balance
- Periodic Vibration Checks
- Continual Vibration Monitoring
- Engine Performance Checks with automatic nomograph and margin calculations
- Continual Aircraft & Engine Parameter Monitoring
- 1553 Databus interface
- Interface to Control Display Navigational Unit (CDNU) via the 1553 databus
- On Board Go/No Go indications with simple user interface for the aircrew
- Ground Station Software with Go/No Go indications, data archival, data review & analysis

Features with immediate payback

# RT&B Displays



- Polar Plot Display
- Track Display
- Measurements & Solution Display
- Adjustments



Improves Troubleshooting Capability

- **User definable configurations via Engineering Ground Station Software**
- **Multiple alarming levels, which drive visibility to aircrew**
  - Master Caution Panel
  - On CDNU Display
  - On AIMS Acquisition Unit
  - On Ground Station



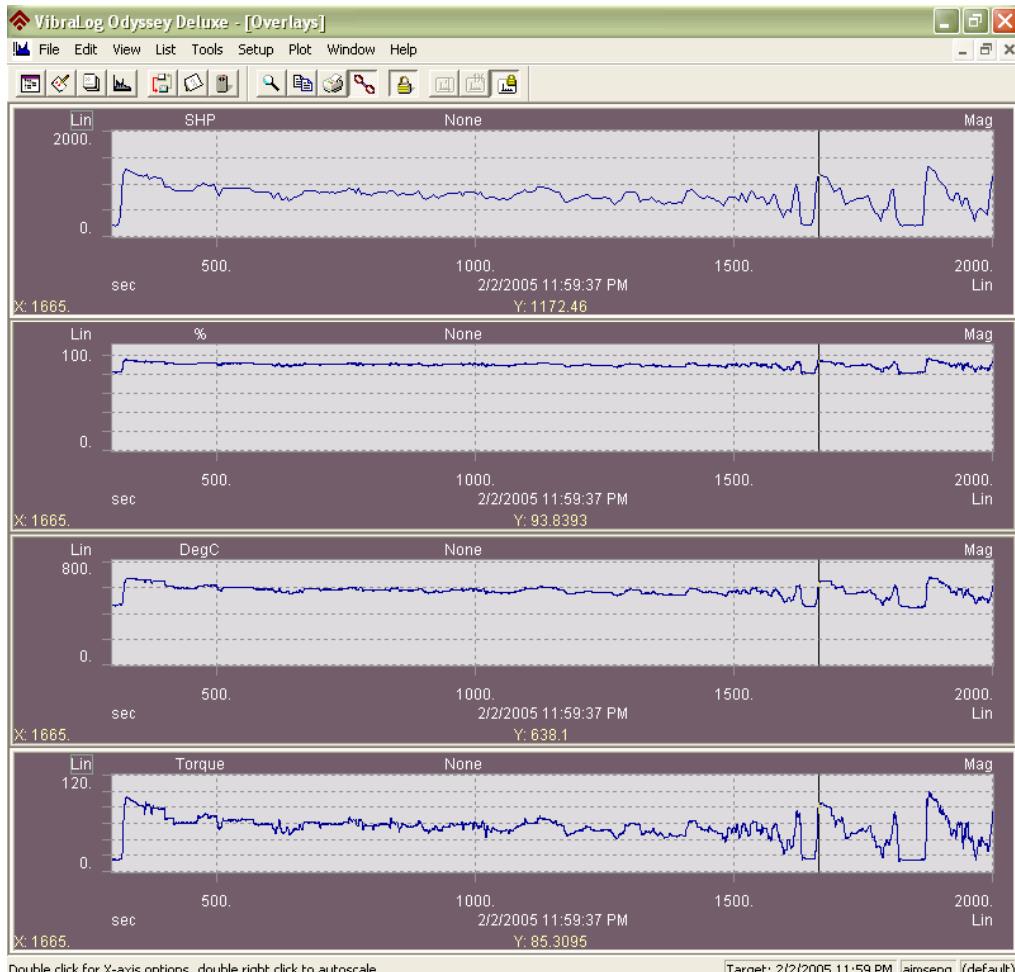
**Immediate Feedback of Alarm Conditions**

# Periodic Checks & Continual Monitoring



- **Monitors:**

- Engine and Drivetrain Vibration Levels
- Overspeeds
- Overtorques
- Overtemperatures
- Chip and Debris Screen States
- Oil Temperature and Pressure
- Engine Performance Margin
- Air Data (OAT, PA, KIAS via 1553B data bus interface)

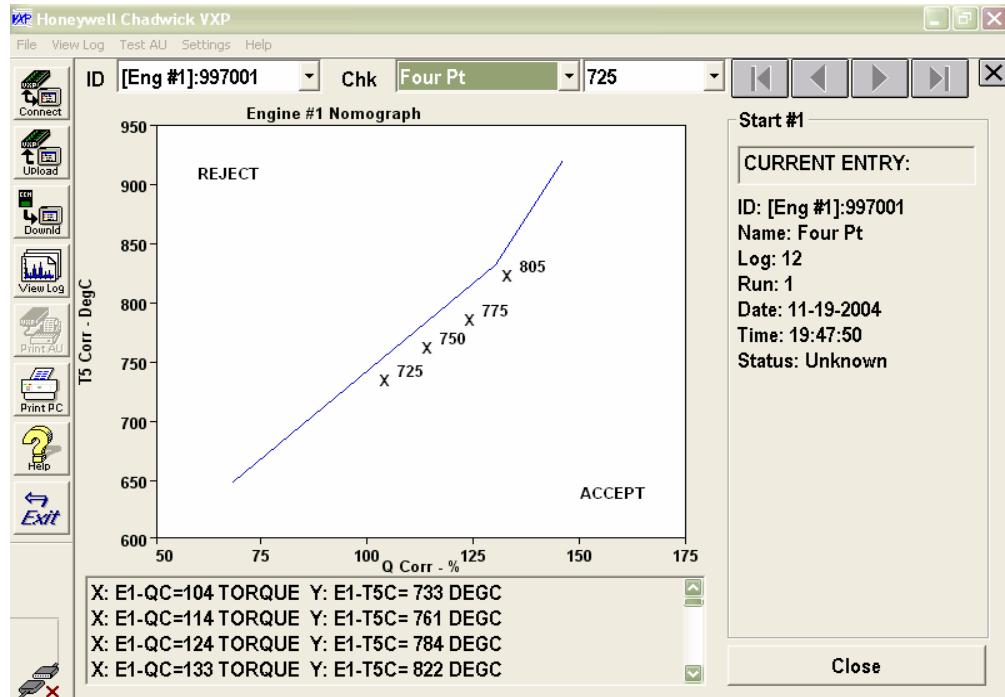


Increasing Safety & Reliability

# Engine Check Displays



- Engine performance assessed on-board, resulting in immediate feedback of acceptability
- Complete post maintenance check flight engine setup



- Migrating towards fully automated performance margin on the fly
  - Potentially eliminating phase performance check requirement
  - Potentially aiding mission planning efforts

**Eliminate Manual Data Entry and Plotting of Data Points**

# AIMS Savings Realized



- **Annual FCF hours using AIMS will be reduced by 1117 hrs resulting in a savings of \$10,938,505 based on FY04 data**
- **FCF setup time; In addition, the time savings will easily surpass 8,000 man hours annually required to set up for FCF's**
- **SE savings: calibration, repair, fleet readiness**
- **AIMS monitor feature has potential to uncover component anomalies, prior to catastrophic failure, inherently save parts and will increase safety**

**Features with immediate payback**

# Conclusion



# System Selection Critical



- Automation is good to a point
- No COTS system is 100% ready to go
- Demand control of configurations (routes & limits)
- Control getting drowned in mass amounts of data
- The system must cater to the operator and maintainer
- More is not necessarily better
- Must be simple at end user
- Must inform the operator/maintainer of pending problems or failures
- Grow the system as lessons are learned
- Off site analysis is not practical
- Must conform to new software requirements - NMCI

Understand how your system works for you

- Advanced Gearbox Diagnostics
- Monitoring of flight controls
- Flight regime recognition for engine performance calculations
- Automation of data management, diagnostics and prognostics
- RT&B “SmartChart” Technology - Tell the maintainer what is wrong with the aircraft

# Benefits are tangible



- **Significant Cost Savings**
- **Achieved highest readiness rating**
- **Engine availability improved**
- **Back shop procedures improved**
- **Safety of flight improved**

**We have realized a significant return**

# Questions?

